Aeroelastic Calculations of Quiet High-Speed Fan Performed

An advanced high-speed fan was recently designed under a cooperative effort between the NASA Glenn Research Center and Honeywell Engines & Systems. The principal design goals were to improve performance and to reduce fan noise at takeoff. Scale models of the Quiet High-Speed Fan were tested for operability, performance, and acoustics. During testing, the fan showed significantly improved noise characteristics, but a self-excited aeroelastic vibration known as flutter was encountered in the operating range. Flutter calculations were carried out for the Quiet High-Speed Fan using a three-dimensional, unsteady aerodynamic, Reynolds-averaged Navier-Stokes turbomachinery code named "TURBO." The TURBO code can accurately model the viscous flow effects that can play an important role in various aeroelastic problems such as flutter with flow separation, flutter at high loading conditions near the stall line (stall flutter), and flutter in the presence of shock and boundary-layer interaction.

Initially, calculations were performed with no blade vibrations. These calculations were at a constant rotational speed and a varying mass flow rate. The mass flow rate was varied by changing the backpressure at the exit boundary of the computational domain. These initial steady calculations were followed by aeroelastic calculations in which the blades were prescribed to vibrate harmonically in a natural mode, at a natural frequency, and with a fixed interblade phase angle between adjacent blades. The AE-prep preprocessor was used to interpolate the in-vacuum mode shapes from the structural dynamics mesh onto the computational fluid dynamics mesh and to smoothly propagate the grid deformations from the blade surface to the interior points of the grid. The aeroelastic calculations provided the unsteady aerodynamic forces on the blade surface due to blade vibrations. These forces were vector multiplied with the structural dynamic mode shape to calculate the work done on the blade during one vibration period, then this result was converted to an aerodynamic damping. Flutter occurs when the aerodynamic damping becomes negative, if structural damping is ignored.

The results of these aeroelastic calculations are summarized in this plot of aerodynamic damping versus mass flow rate at a constant rotational speed. As the backpressure is increased, the mass flow rate through the fan decreases and the fan operating point moves towards the stall line. The aeroelastic calculations showed that the aerodynamic damping decreases as the stall line is approached, as observed during testing. In addition, the aeroelastic calculations with the TURBO code correctly predicted the aeroelastic parameters: the most unstable vibration mode and interblade phase angle, as observed during testing.

The Quiet High-Speed Fan demonstrated significant noise reductions during testing, but flutter imposed limits on its operating range. The accurate calculation of the aeroelastic characteristics using the TURBO code is a significant step toward eliminating flutter from the operating range and toward realizing the benefits of reduced fan noise. The aeroelastic

calculations described here were performed under a grant by University of Toledo researchers in collaboration with Glenn's researchers.
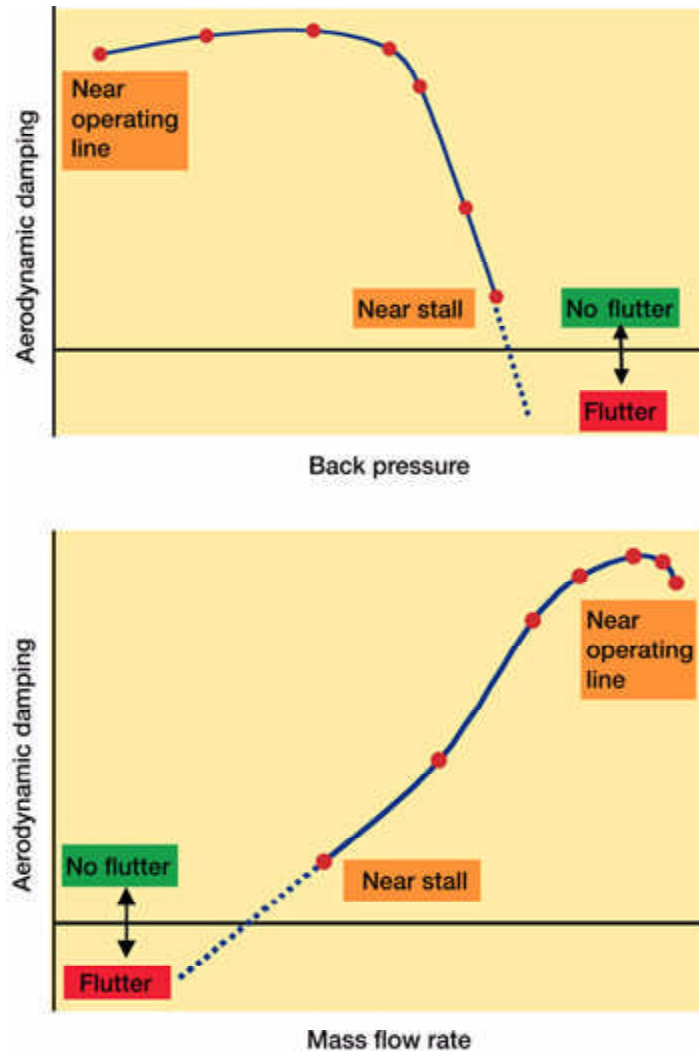
Aeroelastic characteristics as calculated using the TURBO code.
Long description: This plot of calculated aerodynamic damping versus mass flow rate at a constant rotational speed shows that the aerodynamic damping decreases as the mass flow rate through the fan decreases. As the mass flow rate is decreased as a consequence of increased backpressure, the operating point moves from a near-operating-line condition to a near-stall condition on the fan map. If structural damping is ignored, flutter occurs as the aerodynamic damping becomes negative. Flutter, no flutter, near stall, and near operating line conditions shown.

University of Toledo contacts: Dr. Milind A. Bakhle, 216-433-6037, Milind.A.Bakhle@grc.nasa.gov; and Dr. Rakesh Srivastava, 216-433-6045, Rakesh.Srivastava@grc.nasa.gov
Glenn contacts: Oral Mehmed, 216-433-6036, Oral.Mehmed@grc.nasa.gov; and Dr.

James B. Min, 216-433-2587, James.B.Min@grc.nasa.gov

Authors: Dr. Milind A. Bakhle, Dr. Rakesh Srivastava, Oral Mehmed, and Dr. James B. Min

Headquarters program office: OAT

Programs/Projects: UEET, QAT, Propulsion Systems R&T